Experience-Based Lecture of Vibration Engineering Using Dual Scale Experiments: Feeling the Free Vibration of 5,600-ton Seismic Building and Controlling the Vibration of Scale-Down Experimental Model

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***Abstract*—This Innovative Practice Full Paper presents an experience-based lecture style for vibration engineering. In the proposed style, experiments of the free vibration using a seismic building and advanced vibration control using an effective device are provided in combination. In the first trial of this lecture style in 2015, two hundreds of second-year students felt the free vibration of the five-story building with a weight of 5,600 ton inside the building and witnessed the mechanism of the isolation layer. To follow the demonstration experimentally, we have built an experimental system. The device is composed of a vibration component corresponding to a building and a cart with a handle corresponding to the ground. They are connected via a linear actuator which can exert one-dimensional force to the vibration component as a function of the input voltage. Students oscillate the cart and observe the motion of the vibration component. In addition, the system has virtual reality cameras to attract students' interest. The lecture was conducted in 2017. A questionnaire showed that 100% of students valued the lecture as useful. Since 90% of students valued that providing large-scale demonstration and this lecture in combination as useful, the proposed style achieved a certain result.**

I. Introduction

In engineering education fields, teaching methods to motivate student are quite important. To satisfy the requirements to be an expert, students need strong theoretical foundations as well as practical skills. It has been revealed that traditional teaching styles that mainly rely on what we refer to as non-interactive and passive approaches, such as lectures, homework assignments, and tests, do not produce effective educational results [1]. An individual student's in-class learning depends on his or her innate abilities and interests in the topic [2]. Since there is a tendency to forget what is simply said or shown, we sometimes introduce items like pictures or videos in class to motivate students. Several approaches have been proposed for a smooth transition from lecture-based knowledge received in classrooms to practical skills used for research. In a flipped classroom, students work on learning

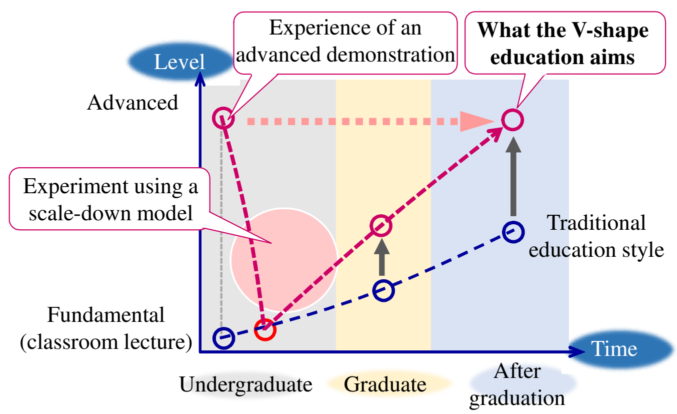

Fig. 1. The V-shape education style execution flow chart.

materials that they previously explored independently [3]. A blended learning style that combines online digital media with traditional classroom methods [4], [5], [6], [7] was experimentally demonstrated [8]. These two approaches are related because teaching contents are provided outside of the classroom. An effective lab-based teaching style using student-generated videos was proposed [9]. In addition, using well-designed classroom lectures and outside activities enhanced students' motivation and created better learning experiences [10]. In this paper, we suggest an educational style that boost students' motivation to learn subjects, and elevates their abilities in laboratories and post-graduation.

We suggest a lecture style referred to as "V-shape education style." Figure 1 shows an execution flow chart for this proposed style. Unlike a traditional teaching style in which the content level is gradually developed, thus drawing an upward curve, the V-shape education style includes an advanced demonstration of a given technology at the very

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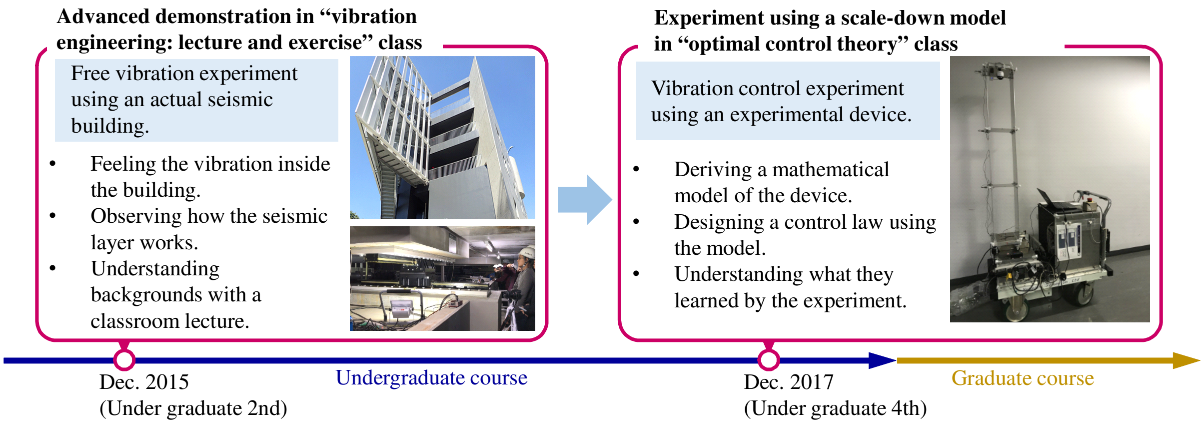


Fig. 2. Education flowchart using dual-scale experiments.

beginning of a lecture. Students observe one of the largest experiments first hand and learn its academic background. The experience motivates students to learn in subsequent lectures and accelerate their knowledge. The first opportunity for students to use what they've learned would be in their graduate work. To support their work, the V-shape education style also provides a scaled-down model experiment based on the advanced demonstration at an appropriate timing. Students use an experimental device to review what they learned and experienced during the demonstration. In addition, students also attempt to install another algorithm into the device that cannot be adopted to the larger experiment, and thus develop skills using hardware and software that interact with the computers' external devices, such as sensors, actuators, and user-interface elements. Students who participate in a V-shape education-based curriculum are expected to develop higher skills than their peers. The device supports students to understand what they learned through the experiment. Moreover, unlike passive vibration control used in the experiment, an active control using an actuator can also be conducted. This paper describes an experimental set to profile the use of the vibration engineering lecture based on the V-shape education style launched in 2015 [11], [12]. We show an education flowchart based on the V-shape style in Fig. 2 that employs dual-scale experiments. As a large scale demonstration of an advanced technology, students experience a free vibration of an actual seismic building in a part of "vibration engineering: lecture and exercise" class at their 2nd year of the undergraduate course. After two years, part of the students conduct an experiment using a scale-down experimental device in a part of "optimal control theory" class at their 4th year of the undergraduate course. This paper reports both of two experiments and overall effect of the educational style.

In this paper: Section II describes a free vibration experiment using an actual seismic building. The lecture details and questionnaire results are discussed. In section III, we describe an experiment using a scaled-down model of the seismic building. The device we developed for the experiment is briefly reviewed with a mathematical model for numerical simulations. In addition, we also describe the virtual reality system that offers students a visually rich experience. Section IV reports on the lecture using the developed device. Questionnaire results are also examined. Section V concludes this paper with a brief discussion.

Fig. 3. Seismic building used for a free vibration experiment [13].

II. Free Vibration Experiment Using 5,600 tons of Seismic Building

A. Overview

The first trial of the vibration engineering lecture based on the V-shape education style was demonstrated in 2015. Figure 3 shows an outside view of the seismic building used for the experiment [13]. The building is five stories high and weighs 5,600 ton. It has a base isolation layer composed of cross linear bearings, laminated rubber bearings, and oil dampers. By using the isolation mechanism, the building can handle maximum scale earthquakes registering a magnitude of 9 on the Richter scale. In addition, free vibration experiments on the building can be conducted with oil jack loading systems in the seismic layer. Figure 4 shows examples of displacement response of the free vibration experiment [11]. Without oil

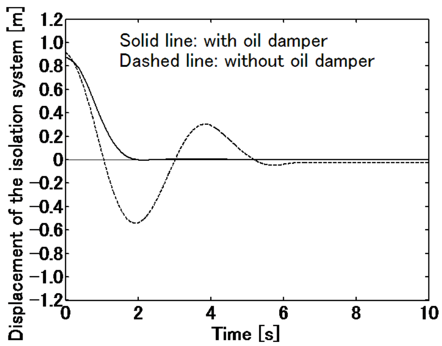


Fig. 4. Examples of displacement response [11].

Fig. 5. Observation of the seismic layer of the building.

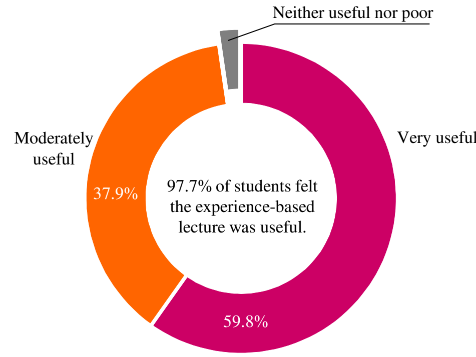


Fig. 6. Was the experience-based lecture on free vibration using the seismic building useful to you?

TABLE I
WHAT PARTS OF LECTURE USING THE ACTUAL SEISMIC BUILDING DID YOU FIND PRODUCTIVE? (SELECT ALL RESPONSES THAT APPLY TO YOU)

Experiences that cannot obtain through typical classroom lectures were good.	79.3%
The ability to generate interest in earthquakes, disaster mitigation, and architecture was good.	52.9%
The ability to generate interest in vibration engineering was good.	37.9%
The experiment experience was better than items captured on the Internet such as videos.	28.7%
The lecture may help us to understand what we've learned in typical classroom lectures.	28.7%
The combination of the experience, numerical simulations, and classroom lecture was good.	21.8%

dampers, the building becomes underdamped system and the vibration gradually taper off to zero. With oil dampers, the building becomes a critical damped system. In both cases, the displacements were around 0.9 m. Students experiences the vibration of this critical damped system.

At present, the lecture is offered to all the second-year students in the mechanical and aerospace engineering course. Approximately two hundred students attended the lecture. Students were divided into two groups and one felt the artificial free vibration inside the building and the other witnessed first-hand how the isolation mechanism works. Two groups alternated the roles and all students experienced the vibration in two ways. Figure 5 shows a photo from the experience-based lecture. On the same day, there was a classroom lecture inside the building that explained more about the experiment. During the lecture, the experiment was numerically simulated and the experiment's academic background was explained. Questionnaires were also distributed to determine the lecture's effectiveness and gather suggestions for improvements.

B. Questionnaire Results

The questionnaire results are briefly reviewed here. Figure 6 illustrates students' impressions of the experience-based lecture. The result indicate that the lecture was favorably received by 97.7% of the students. In particular, 59.8% of the students assessed the lecture as very useful. In addition, 37.9% of the students felt the experiment was moderately useful. Though 2.3% of the students (two students) responded *was neither useful nor poor*, nobody indicated the experiment was poor. Table I summarizes the students' descriptions of why they felt the experiment was useful, with responses ordered according to the rating. Overall, 79.3% of the students assessed the experience as one they cannot obtain through typical classroom lectures. Since the seismic building is the facility in which disasters are simulated, 52.9% of the students developed an interest in earthquakes, disaster mitigation, and architecture. In addition, 37.9% of the students answered that they became interested in vibration engineering. Though the experiment was positively received, only 28.7% of the students indicated that it had a particular advantage over photos or videos found on the Internet. Only a small percentage of students (28.7%) felt the experiment helped them understand what they learned in typical lectures. The 90-minute lecture included the experiment, numerical simulation, and classroom discussion; there may be room for improvement in the content balance. Only 21.8% of the students assessed providing several materials. It is not uncommon these days to introduce several items during a lecture to motivate students, therefore few students assessed this factor. In addition, we had 31 comments on the lecture

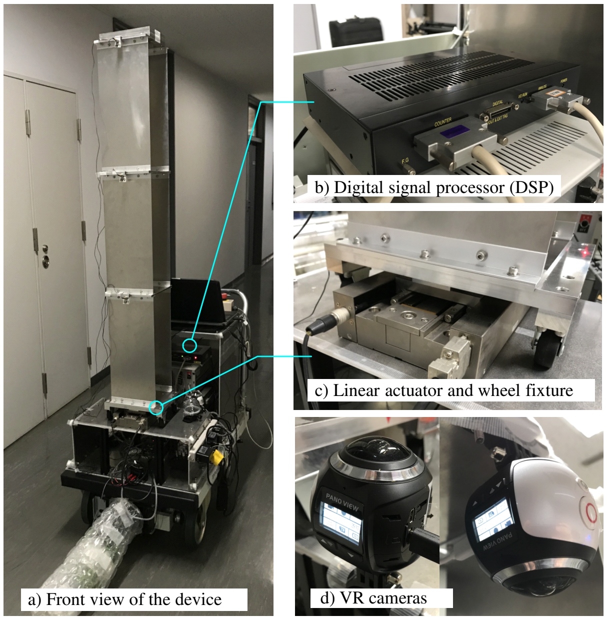


Fig. 7. Photo of the scale-down experimental device.

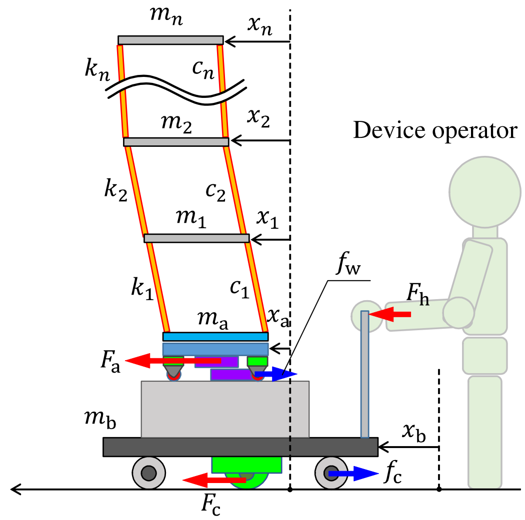


Fig. 8. Mathematical model of the experimental device.

from students. As the results indicate, the experience-based lecture was positively received. We have been working for three years to improve the lecture style [12].

III. Vibration Control Experiment Using a Scale-Down Model

As described in Section I, the V-shape education-based curriculum provides an experiment using a scale-down model of a large-scale experiment. To perform an effective scaled-down model experiment, we designed an experimental device and lecture plan.

A. Device Overview

We developed an experimental device shown in Fig. 7. Figure 7 a) is the device's front view. The device is comprised of a vibration component, which accounts for the building, and a motor cart, which accounts for the ground. They are connected to a linear actuator that exerts a force on the vibration component. During the experiment, an experimenter grabs the handle and shakes the device.

The vibration component is a single bay several-story frame with columns (blade springs) of equal firmness at the side. The blade springs are made of aluminum with an average cross section of 2.0 mm by 200 mm and the floors are also made of aluminum plates attached to the springs. Each floor has an acceleration sensor to detect the horizontal component of the floor acceleration. A bay is fixed to the other floor by bolts and nuts, and the number of stories can be easily changed as per requirements. For simplicity, the three-story vibration component is used for the lecture. The motor cart has a separate power supply, which allows the experiment to be conducted anywhere. An assist system to help the experimenter is powered by portable batteries used with power-assisted bicycles. Strain gauges mounted on the handle sense human force and an assistance force is calculated and added to shake the experimental device so little human force is needed. The cart also has portable batteries that power the linear actuator, laptop computer, and digital signal processor (DSP) (Fig. 7 b). The linear actuator that connects the vibration component and motor cart exerts a force as a function of the input voltage. To take the weight load off of the actuator, the vibration component is mounted on a fixture with four wheels (Fig. 7 c). The DSP adjusts the number of motor rotations in the linear actuator and motor cart, as well as each roof's accelerations, and controls each actuator. Additionally, two virtual reality (VR) cameras are used to support students' learning (Fig. 7 d). The VR technology is now widely used in entertainment [14], industry [15], and even education [16], [17]. One VR camera is mounted on the top floor roof and is pointed down on the motor cart. Another camera is mounted on the motor cart and is pointed up on the vibration component. These cameras transmit real-time videos via a wireless network to VR headgears. Unlike just observing the vibrating experimental device from outside, the students' vision is scaled down so they can witness first-hand how the vibration component vibrates, how the linear actuator works, and how the vibration is absorbed. In addition, the VR system supports our efforts to motivate students by using a visual building vibration experience, if a free vibration of the actual seismic building is not possible.

B. Mathematical Model and Control Method

Figure 8 illustrates the mathematical model for the n-story device. The motion equations that describe the behavior of the vibration component are

$$\ddot{x}_i = \frac{k_{i+1}}{m_i}x_{i+1} + \frac{c_{i+1}}{m_i}\dot{x}_{i+1} - \left(\frac{k_i}{m_i} + \frac{k_{i+1}}{m_{i+1}}\right)x_i - \left(\frac{c_i}{m_i} + \frac{c_{i+1}}{m_{i+1}}\right)\dot{x}_i + \frac{k_i}{m_i}x_{i-1} + \frac{c_i}{m_i}\dot{x}_{i-1}, \qquad (1)$$

TABLE II
PHYSICAL PARAMETERS OF THE EXPERIMENTAL DEVICE.

Parameters	Value
m_i $(i=1,\cdots,n-1)$	2.01 kg
m_n	3.52 kg
m_{a}	5.82 kg
k_i $(i=1,\cdots,n)$	2.28×10^3 N/m
c_i $(i=1,\cdots,n)$	1.50 Ns/m
K_{a}	2.51 N/V
f_{c}	35.0 N
M	133.2 kg

$$\ddot{x}_n = -\frac{k_n}{m_n}x_n - \frac{c_n}{m_n}\dot{x}_n + \frac{k_n}{m_n}x_{n-1} + \frac{c_n}{m_n}\dot{x}_{n-1}, \quad (2)$$

$$\ddot{x}_{\mathrm{a}} = (k_1x_1 + c_1\dot{x}_1 - k_1x_{\mathrm{a}} - c_1\dot{x}_{\mathrm{a}} + K_{\mathrm{a}}e_{\mathrm{a}} - f_{\mathrm{w}})/m_{\mathrm{a}}, \quad (3)$$

$$\ddot{x}_{\mathrm{b}} = (F_{\mathrm{h}} + F_{\mathrm{c}} + f_{\mathrm{w}} - f_{\mathrm{c}})/m_{\mathrm{b}} \quad (4)$$

where x_i is a displacement of the i-th roof, x_{a} is the displacement of the linear actuator, x_{b} is the motor cart displacement, k_i, c_i, and m_i are the spring coefficient, damping coefficient, and mass of the i-th floor, K_{a} is a thrust constant of the linear actuator, e_{a} is an input voltage for the linear actuator, F_{h} is the human force, F_{c} is the motor cart's assist force, f_{w} is a Coulomb friction force exerts on the linear actuator, and f_{c} is a Coulomb friction of the motor cart wheel. Table II summarizes the device parameters. Figure 9 shows a block diagram of the experimental system. Note that $\boldsymbol{x}_{\mathrm{c}} = [x_{\mathrm{b}}, \dot{x}_{\mathrm{b}}]$ is the state vector of the motor cart, $\boldsymbol{x}_v = [x_1, \dot{x}_1, \cdots, \dot{x}_{\mathrm{a}}]$ is the state vector of the vibration component, $\boldsymbol{A}_v$ is the state matrix of the vibration part, and $\boldsymbol{f}_{\mathrm{b}}^*$ and $\boldsymbol{f}_{\mathrm{b}}$ are the feedback gains of an active and passive control, respectively. An impedance control theory that assist human force F_{h} to shake the cart, reaction force controller, and disturbance observer for a noise reduction are implemented and support the experiment. The linear actuator operation is based on a generated force that is related to the input voltage; the control strategy is selected so that the force can minimize a given roof's velocity. The strategy to determine the input voltage can be adjusted to suit the lecture purpose.

C. Lecture planning

The lecture is conducted as a part of the optimal theory classes. During the the free vibration experiment in 2015, few participants felt the experiment helped them understand typical lectures (28.7%). To address this response, we proposed two-day lectures to quantitatively and qualitatively enhance the content. The first lecture day is an experience-based classroom lecture that entails learning the experiment's academic background and performing numerical simulations. During the second lecture day, students conduct an active vibration control experiment using the device.

The first lecture day includes learning fundamental backgrounds, fundamental programming skills, and how to design the controller. Students review the 2015 free vibration experiment on the actual seismic building to recall what they learned two years ago. After a brief review, students better understand the experimental device by deriving the device's motion equations (Eqs. (2)–(4) in Section III-B). In addition, they learn how to model the 2015 experiment with the scaled-down experimental device. Oil dampers and rubber bearings are modeled as a spring and damper using the linear actuator. Students also watched a video on the scaled-down experiment. This experiment would support students who did not learn about the experiment's academic background in 2015. The final part of the first day's lecture prepares students for the active vibration control conducted during the second lecture day. The principle of vibration control using a linear quadratic regulator (LQR) is explained. Since students learned about the LQR in the optimal control theory classes a few weeks prior to the lecture, adopting the LQR might facilitate understanding. A cost function of the LQR is

$$J = \int_0^{\infty} (\boldsymbol{x}^{\mathrm{T}}\boldsymbol{Q}\boldsymbol{x} + re_{\mathrm{a}}^2)\mathrm{d}t \quad (5)$$

Students explore the matrix $\boldsymbol{Q}$ that minimizes the acceleration of the vibration component by using a numerical simulation tool the instructor provides. Note that $r = 1$ is used. Since we use a three-story vibration component, the form of the state vector is $\boldsymbol{x} = [x_1, \dot{x}_1, \cdots, x_{\mathrm{b}}, \dot{x}_{\mathrm{b}}]$. Students follow provided clues and simulate the device behavior using several kinds of $\boldsymbol{Q}$. The feedback gain for an active control is obtained by using MATLAB® LQR design function. As an example of a weight $\boldsymbol{Q}$, we provide the following formula:

$$\boldsymbol{Q} = \left(\begin{array}{c|ccccc} 0_{5\times5} & & & 0_{5\times5} & & \\ \hline & q_v & 0 & -q_v & 0 & 0 \\ & 0 & q_{\mathrm{p}} & 0 & -q_{\mathrm{p}} & 0 \\ 0_{5\times5} & -q_v & 0 & q_v & 0 & 0 \\ & 0 & -q_{\mathrm{p}} & 0 & q_{\mathrm{p}} & 0 \\ & 0 & 0 & 0 & 0 & 0 \end{array}\right) \quad (6)$$

Equation (6) leads $\boldsymbol{x}^{\mathrm{T}}\boldsymbol{Q}\boldsymbol{x} = q_v(\dot{x}_3 - \dot{x}_{\mathrm{a}})^2 + q_{\mathrm{p}}(x_{\mathrm{a}} - x_{\mathrm{b}})^2$ that minimizes the difference in the velocities of the third roof and linear actuator, and the displacement between the linear actuator and motor cart. After the first lecture day, students will develop the necessary background required for the second lecture day's experiment.

The majority of the second lecture day focuses on experiments using the device. After a quick review of the first day's lecture, students form small groups and discuss the experiment. The group consists of one device operator who shakes the motor cart, and two observers who use the VR equipment to note how the LQR works to absorb the vibration. Students alternate roles throughout the experiment. The students are required to answer a questionnaire for review and feedback.

IV. LECTURE AND QUESTIONNAIRE RESULTS

Twenty fourth-year students took part in the lecture, which represents 10% of the students who experienced the free

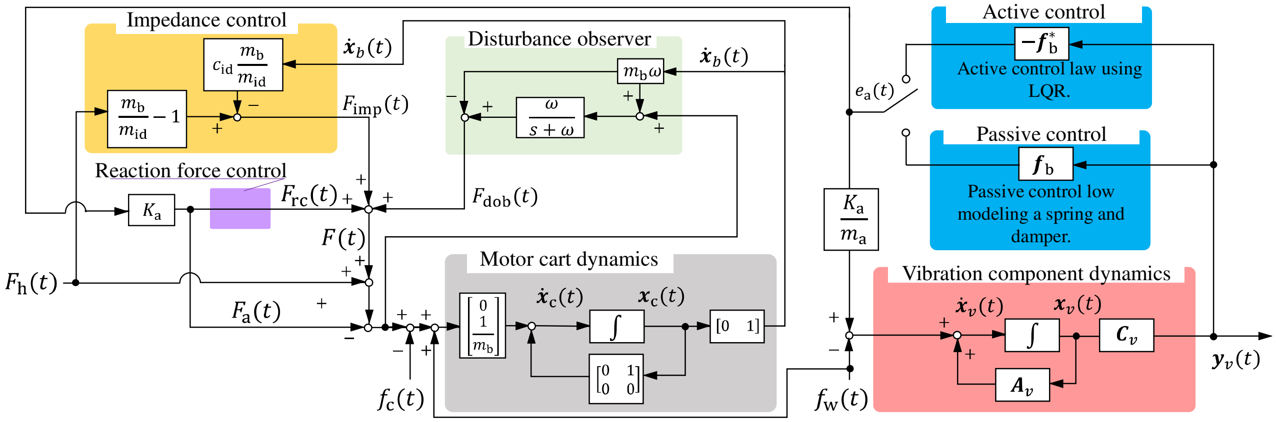


Fig. 9. Block diagram of the control system.

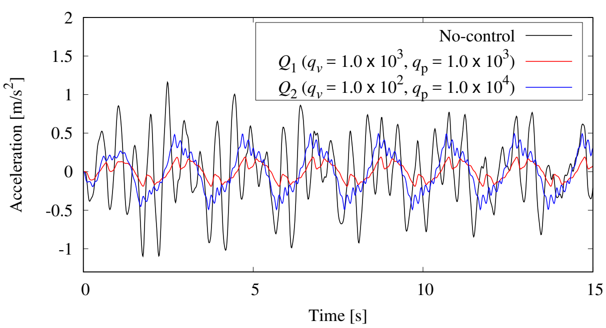


Fig. 10. Acceleration of the third floor calculated using the simulation tool.

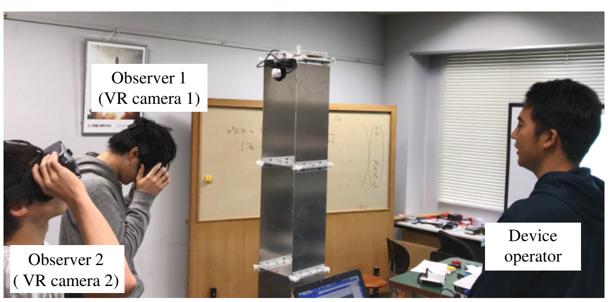


Fig. 11. Experiment conducted by a student group.

vibration of the seismic building in 2015. Correcting opinions from students who attended the experiment in 2015 is useful to investigate the effectiveness of the lectures employing dual-scale experiments. As planned, during the first lecture day, students reviewed the academic backgrounds and designed the LQR controller using the numerical simulation tool. Figure 10 shows accelerations of the vibration component's third floor simulated using the provided tool. Students changed the value of the weight matrix components $\boldsymbol{Q}$ and calculated the acceleration as in Fig. 10. During the second lecture day, students performed the experiment independently (Fig. 11). Each group was comprised of two observers and one device operator, and students alternated roles. One group spent about 5 min for the experiment. The others observed the experiment from outside or checked the real-time video taken by the other camera which is mounted under the vibration component. Students' impressions were investigated following questionnaires.

A. Students' impressions of the lecture based on the V-shape education style

We asked the following three questions to determine whether the desired general objectives were achieved:

a) Did you find the lecture using the experimental device useful?
b) How did it feel to observe the experiment using the VR system?
c) Did you find the lecture approach that combined the actual seismic building and experimental device to be useful?

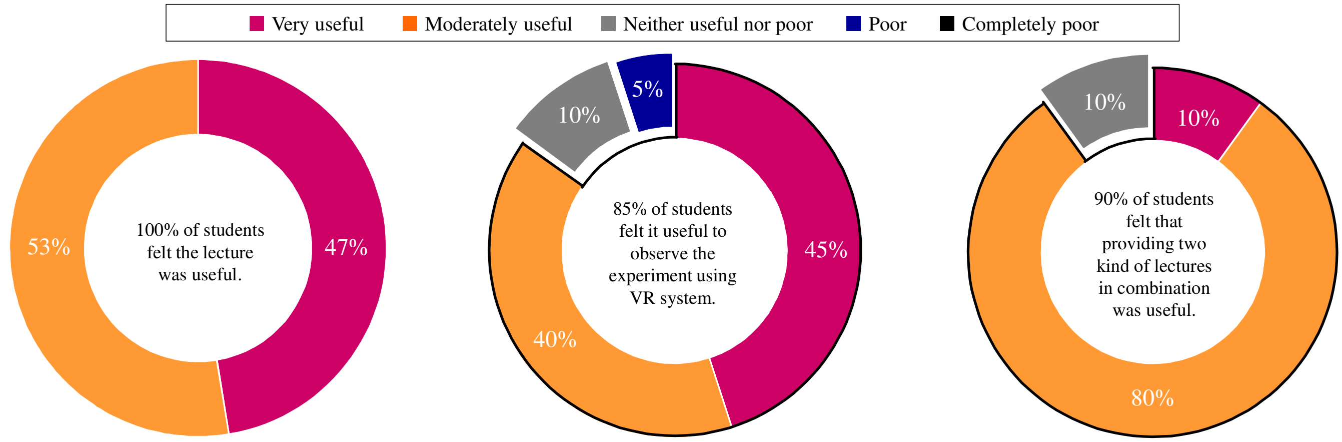
The options were:

- Very useful
- Poor
- Moderately useful
- Completely poor
- Neither useful nor poor

Figure 12 summarizes the students' responses to the questions a)–c). Figure 12 a) indicates that the red area (47%) represents the percentage of students who found the lecture to be very useful. The next orange area (53%) represents the percentage of students who found the lecture to be moderately useful. The result indicated that all students reacted positively to the lecture. Figure 12 b) indicates how students felt observing the experiment using the VR system. Overall, 45% of the students found the VR system to be very useful, and 40% found it moderately useful. Students reacted more or less positively about using the VR system. Figure 12 c) describes how students felt about lectures using the seismic building and experimental device in combination. Overall, 90% of the students felt that providing two lectures in combination was very (10%) or moderately (80%) useful. These three results indicate that the lectures' desired objectives were achieved.

B. Useful aspects of the lecture

Table III lists the aspects that students assessed as useful, which are ordered according to the rating. Note that students



a) Did you find the lecture using the experimental device useful?

b) How did you feel to observe the experiment using VR?

c) Did you find the lecture approach that combined the actual seismic building and experimental device to be useful?

Fig. 12. Questionnaire summary.

TABLE III
WHAT ASPECTS OF THE LECTURE USING THE EXPERIMENTAL DEVICE DID YOU FIND USEFUL? (SELECT ALL THAT APPLY TO YOU)

Experiences that can't be obtained in typical lectures were good.	63.2%
The experiment experience was better than items found on the Internet such as videos or photos.	42.1%
The ability to gain interest in control engineering was good.	36.8%
The lecture helped us to understand what we learned during typical lectures.	36.8%
The combination of experience, numerical simulation, and classroom lectures was good.	26.3%
The ability to gain interest in vibration engineering was good.	15.2%

selected all options that applied to them. As table III indicates, 63.2% of the students found this to be a special experience that cannot be obtained in typical classroom lectures. In addition, 42.1% of the students felt that the experiment was better than items found on the Internet like videos or photos. Meanwhile, 36.8% of the students felt that the lecture would help them to understand the content of typical classroom lectures. Since it's more common today to introduce experiments and simulation into a classroom lecture, only 26.3% of the students selected this option. In addition, there was a 21.6 point difference between the number of students who became interested in control engineering (36.8%) and in vibration engineering (15.2%). The lectures were held during the last two optimal control theory sessions at our university. In addition, during the first lecture day, students learned about the LQR that formed the backbone of the active vibration control. This knowledge could work as unconscious bias and students might not be aware of the lecture's vibration engineering aspects.

TABLE IV
WHY WAS IT USEFUL TO USE THE VR SYSTEM? (SELECT ALL OPTIONS THAT APPLY TO YOU)

The VR system provided a view as if one was inside the device.	58.8%
I could feel the device vibration using the VR system.	52.9%
The VR system itself is attractive to students.	47.1%
I could feel how control law worked.	23.5%
Observing the experiment using the VR system helped us to understand typical classroom lectures.	11.8%

C. *Useful points of VR system*

Table IV list the students' responses as to why they found the VR system useful. Note that students who responded to the previous question c) as very or moderately useful also answered this question. Fortunately, 58.8% of the students assessed the sight scale-downed by the VR system. Overall, 52.9% of the students thought that the VR system helped them to feel the device vibration. The following opinion is that the VR system itself is attractive to students (47.1%). Overall, 23.5% of the students found the system was useful to observe how control law works. Only 11.8% of students felt that the system helped them to understand typical classroom lectures. Clearly, the results reflect that the visual impression created by the VR system was not useful to support students' understanding of the experiment's academic background.

One of the reasons why the VR system's visual aspects were highlighted might depend on whether the students were accustomed to using VR products. Only one student (5%) responded that he or she frequently used some type of VR

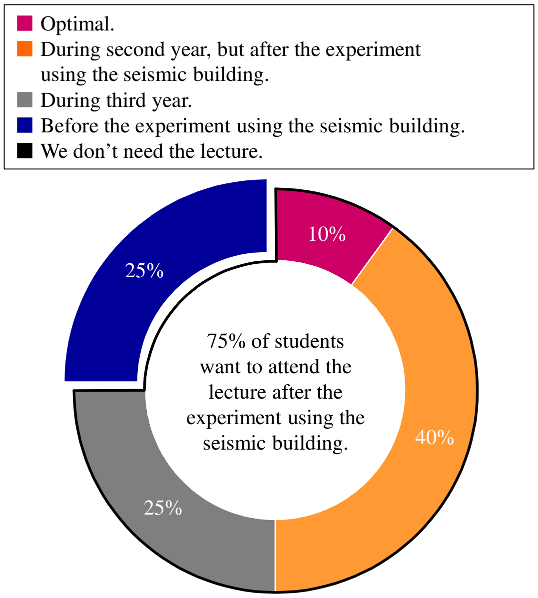


Fig. 13. What is the appropriate timing for students to attend the lecture using the device?

product. Overall, 35% of the students have used VR products, while 60% have never used them. Since 85% of students were not accustomed to using VR products, options reflecting the VR system's visual aspects might have been selected.

In the lecture, low-quality VR videos were shown to observe the experiment in real-time. On the other hand, if we exclude the real-time observation, we can record high-quality VR videos beforehand and show them during lectures. We asked students whether the VR video quality was appropriate for the lecture. The results indicated that most students (89%) agreed with providing low-quality, real-time videos with the VR system. In addition, 26% of the students were also satisfied with the video quality. Meanwhile, 63% of the students didn't like the low-quality video but stated that providing a real-time video was more important. On the other hand, 11% of the students thought that it would be better to watch pre-recorded, high-quality videos using the VR system. The questionnaire results indicated that observing the experiment in real time with the VR system was positively received.

D. Timing to offer the lecture using the experimental device

The final question was about the timing in which the lecture is offered to students. Figure 13 summarizes the students' responses. Of the students who responded, 10% thought that the lecture timing was optimal. Meanwhile, 40% of the students thought that the lecture should be provided during the second year, after the experiment using the seismic building. In addition, 25% of the students thought that the lecture should be provided during the third year. The results indicate that, to varying degrees, 75% of students thought it would be better to offer the lecture after the free vibration experiment on the seismic building. As 40% of the students responded, it may be more efficient to offer the lecture shortly after the experiment using the seismic building. We could shorten the time required for the reviewing process we introduced into the lecture, so that students can strongly associate their experiences in the actual building with the practical skills to operate the device. However, 25% of students felt that the lecture should be provided before the experiment; this rate seems high. Since the intent of the V-shape education style is to support or enhance students' learning by using an experimental device after participating in a large-scale demonstration, this is an unintended result. In the V-shape education style flowchart, the experiment using a scaled-down device is provided between the large-scale experiment and classroom lecture on the topic's academic background. Since this was the first curriculum demonstration based on V-shape education, it was difficult to provide the experiment at an appropriate time. The lecture timing should be optimized in the future. At minimum, we need to explain to students the purpose of the lecture or the V-shape education style.

V. Discussion

In this paper, we proposed a new teaching style referred to as V-shape education to motivate students to learn subjects by providing an advanced demonstration on a technology at the very beginning of a lecture. Students' motivation is also supported by an experiment using a scaled-down device. We designed lectures for vibration engineering based on the V-shape education style and demonstrated lectures using free vibration of the seismic building and vibration control using the experimental device. Questionnaire results indicated that our overall goals were achieved.

The framework to provide lectures based on V-shape education has been established. We are now interested in optimizing the V-shape education-based lecture style. The indicated improvements are follows:

- Strengthen the connection between the experiment with the seismic building and scaled-down model experiment.
- Use the VR system as an effective way to increase students' interests in vibration engineering.
- Optimize the timing of the lecture using the experimental device.

Students who have experienced the dual-scale experiments are mostly now in the 1st year of the graduate course and undertake their researches independently. Students who experienced the free vibration experiment in 2016 will attend an improved version of lecture using the device in 2018. By doing a follow-up study on the changes in students' examination score, motivation for learning, and quality of research, the effectiveness of the lecture style will be investigated.

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